EDGEWOOD

CHEMICAL BIOLOGICAL CENTER

U.S. ARMY SOLDIER AND BIOLOGICAL CHEMICAL COMMAND

ECBC-TR-249

CHARACTERISTICS AND SAMPLING EFFICIENCIES OF AEROSOL SAMPLERS: ROTATING ARM SAMPLER, BIOCAPTURE™ SAMPLER, AND MICROVIC™ AEROSOL CONCENTRATOR

Jana Kesavan
Daryl Jones
Donna Carlile
Robert W. Doherty

RESEARCH AND TECHNOLOGY DIRECTORATE

Tiffany Sutton

STUDENT CONTRACTOR

August 2002

Aberdeen Proving Ground, MD 21010-5424

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	2002 August	Final; 00 Jan - 01 Oct

4. TITLE AND SUBTITLE

Characteristics and Sampling Efficiencies of Aerosol Samplers: Rotating Arm Sampler, BioCapture™ Sampler, and Microvic™ Aerosol Concentrator

5. FUNDING NUMBERS

PR-622384/ACB2

6. AUTHOR(S)

Kesavan, Jana; Jones, Daryl; Carlile, Donna; Doherty, Robert W. (ECBC); and Sutton, Tiffany (Student Contractor)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

DIR, ECBC, ATTN: AMSSB-RRT-TA, APG, MD 21010-5424

8. PERFORMING ORGANIZATION REPORT NUMBER

ECBC-TR-249

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Characteristics and sampling efficiencies of three aerosol samplers were determined. They are Rotating Arm Sampler (RAS), BioCapture™ Sampler, and Microvic™ Aerosol Concentrator. The RAS was made at the U.S. Army Edgewood Chemical Biological Center, and the BioCapture™ and the Microvic™ aerosol concentrator were made by MesoSystems Technology, Inc. (Richland, WA). The RAS samples the aerosol on filters. The BioCapture™ collects the particles on a wetted rotating surface, and the Microvic™ concentrates the particles from an air flow rate of 30 L/min to 3 L/min. A filter is attached to the Microvic™ Aerosol Concentrator to collect the particles. Monodisperse fluorescent oleic acid particles and monodisperse fluorescent polystyrene latex particles were used in these tests. Fluorometry was the analysis method. The results showed that the sampling efficiency of the RAS is between 80-95% for 2-13-μm particles. The sampling efficiency of the BioCapture™ is <22% for particles in the 1-9 μm range, and the sampling efficiency of the Microvic™ is between 40-60% for 1-11-μm particles.

14. SUBJECT TERMS

Aerosol Sampling efficiency Samplers

15. NUMBER OF PAGES

19

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Blank

PREFACE

The work described in this report was authorized under Project No. 622384/ACB2, Non-Medical CB Defense. The work was started in January 2000 and completed in October 2001.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct such requests to the National Technical Information Center.

Acknowledgments

The authors would like to acknowledge John Knapton for his editorial assistance.

Blank

CONTENTS

FIGURES

TABLE

CHARACTERISTICS AND SAMPLING EFFICIENCIES OF AEROSOL SAMPLERS: ROTATING ARM SAMPLER, BIOCAPTURE™ SAMPLER, AND MICROVIC™ AEROSOL CONCENTRATOR

1. INTRODUCTION

Characteristics and sampling efficiencies of three aerosol samplers were determined. The three samplers characterized were, a Rotating Arm Sampler (RAS) designed and fabricated at the U.S. Army Edgewood Chemical Biological Center (ECBC), and two commercially available samplers, BioCapture™ BT-500 Sampler and Microvic™ Aerosol Concentrator, both produced by MesoSystems Technology Inc., Richland, WA. Sampler characteristics such as size, weight, air flow rate, and power consumption were also determined.

The sampling efficiency was determined by comparing samples collected by the sampler to the samples collected by two stationary open face air filters. The performance of a sampler, or the sampling efficiency, is the product of the aspiration (into the inlet), transmission, and collection efficiencies of the sampler. In the tests reported here, the samplers were tested at calm air conditions and the results, therefore, do not include inlet efficiencies at varying wind velocities.

2. TEST PROCEDURE

2.1 Chamber

The sampler characterization tests were conducted in a 70 m^3 bio-safety level 1 chamber (Figure 1) that has ultra-violet light sources to kill biological material. The temperature and the humidity of the chamber can be set and maintained by a computer very easily and accurately.

HEPA filters are used to filter the air entering and exiting the chamber to achieve very low particle concentrations in the chamber. The maximum amount of air flow that can be exhausted from the chamber is approximately 700 cubic ft/min (approximately $2x10^4$ L/min) by the exhaust pump. This rapidly reduces the aerosol concentration in the chamber. There is also a small re-circulation system that removes air from the chamber, passes it through a HEPA filter, and delivers it back to the chamber. This system is useful when the aerosol concentration in the chamber needs to be reduced by a small amount.

Aerosols can be generated outside and delivered to the chamber, or can be generated inside the chamber. The aerosol in the chamber is mixed by a fan before and/or during the experiment.

2.2 Aerosol Generation

Tests were conducted with monodisperse fluorescent oleic acid particles and monodisperse one micron polystyrene latex (PSL) microspheres. The monodisperse fluorescent oleic acid particles were generated using a vibrating orifice aerosol generator (VOAG, TSI Inc., St. Paul, MN). The one micron blue fluorescent PSL particles (Duke Scientific, Corp., Palo Alto, CA) were generated by a 36 jet collision nebulizer. Charges on the particles were neutralized by passing the particles through a radioactive isotope (Kr-85) neutralizer.

A microscopic picture of fluorescent oleic acid droplets on a slide is shown in Figure 2. The measured particle diameter was converted to an aerodynamic particle size using a spread factor (Olan-Figueroa et al., 1982) and the density of fluorescent oleic acid.

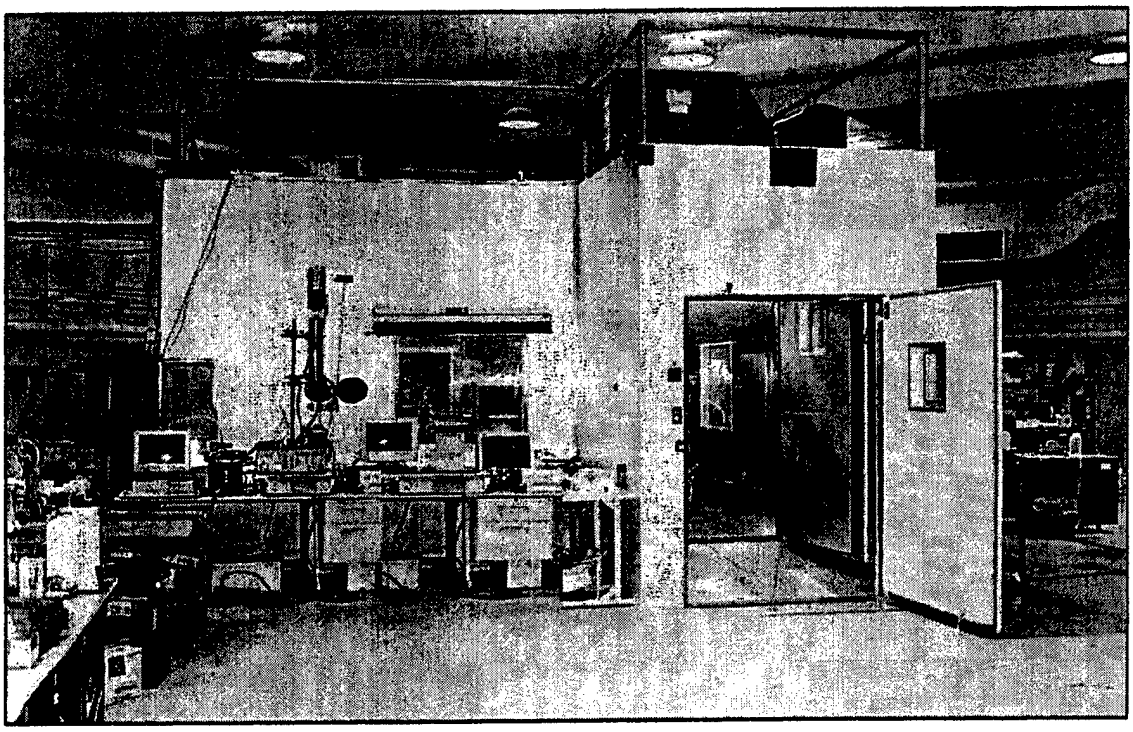

Figure 1. 70 m^3 Aerosol Chamber at ECBC.

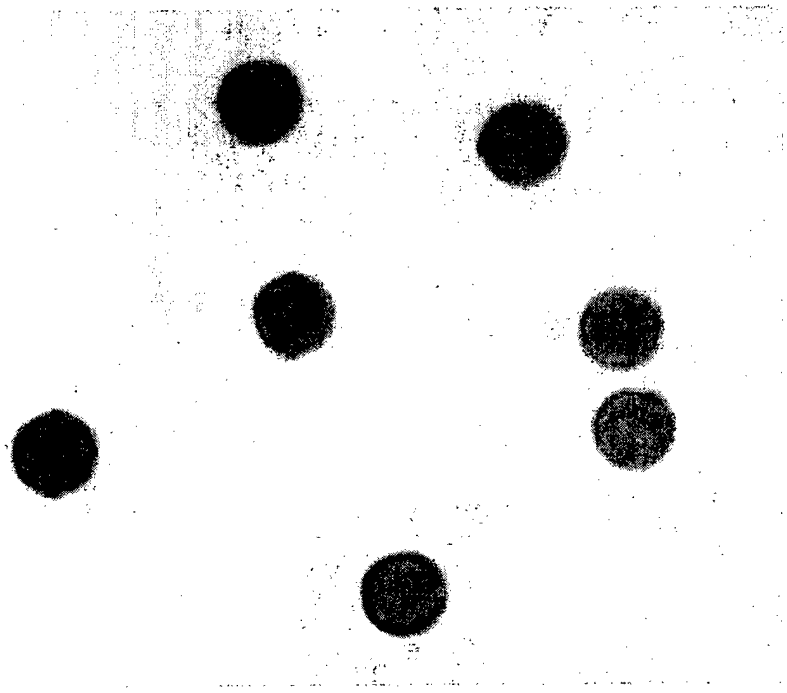

Figure 2. Microscopic picture of fluorescent oleic acid droplets. Droplet size is approximately 10 μm.

2.3 Particle Sampling and Recovery

Glass fiber filters (Pall Corporation, Ann Arbor, MI) were used as reference filters for collecting the fluorescein tagged oleic acid particles. Membrane filters were used as reference filters for collecting the fluorescent polystyrene latex particles (PSL). The air flow rate of the reference filters was measured using an air flow meter (Buck calibrator, A.P. Buck, Inc., Orlando, FL). The samplers and the reference filters sampled the air for the same amount of time, approximately 10 min.

The removal of fluorescein from filters is described in detail by Kesavan and Doherty (2001a). Reference and sample filters were removed from the filter holders, put into a fluorescein recovery solution, and shaken on a table rotator (Lab-Line Instruments, Inc., Melrose Park, IL) for one hour. The fluorescence of the solution was measured using a fluorometer (Barnstead/Thermolyne, Dubuque, IA). The recovery solution used in the tests had equal amounts of alcohol and water and a pH between 8 and 10, obtained by adding a small amount of NH_4OH (e.g., 500 mL of 2-propanol + 500 mL of water + 0.5625 mL of 14.8 N NH_4OH). The removal of fluorescent polystyrene latex particles from membrane filters is described in detail by Kesavan and Doherty (1999). The membrane filters are put into deionized water and hand shaken for 10 sec followed by vortexing for 50 sec. The 60 sec of hand shaking and vortexing were repeated four more times to completely remove fluorescent PSL particles from membrane filters.

Fluorescence of solutions with fluorescent oleic acid and solutions with fluorescent PSL beads were measured with fluorometry. The sampling efficiency was determined by comparing the amount of fluorescein collected by the sampler and the reference filter. The air flow rate of the sampler and the reference filters and the liquid volume of the sample and reference solution were taken into account in the calculation.

3. SAMPLERS AND TEST PROCEDURES

3.1 Size and Operating Characteristics of the Samplers

A summary of the characteristics of the samplers is given in the table.

Table. Operating Characteristics of the Aerosol Samplers.

Characteristic	Rotating Arm Sampler	BioCapture™ BT-500	Microvic™
Air sampling rate: measured, L/min	Probe 1, 31.3 Probe 2, 22.5	150	30
Overall dimensions, inch Length, inch Width, inch Height, inch	 34 22 60	 12 6 8	 2 2 2.5
Weight, lb	not applicable	9	11/16
Power consumption	not applicable	12 V, 3 Ah re-chargeable battery	not applicable

3.2 Rotating Arm Sampler

Pictures of the sampler and dimensions are shown in Figures 3 and 4. Figure 4 shows an enlarged view of the top section. The RAS is mounted on a movable cart to allow convenient transport. The RAS has two arms with attached filter holders. Arm one is 14" long, 16" high, and 9.25" long. Arm two is 11.5" long, 20" high, and 9.25" long. Both arms rotate horizontally around a center of rotation as shown in Figure 4. There are three pullies that can be used to rotate the sampler with rotational speeds of 30, 38, and 47.6 rpm. In this study, we chose the speed of 30 rpm. There is a 4" long 0.94" diameter probe in front of each filter holder. Air flow rates through the filters were 22.5 L/min and 31.3 L/min for the short arm and long arm, respectively. The rotational speed and the volumetric air flow rate through the filter were chosen so that the volume of air covered by the probe opening and the volume of air pulled by the pump were similar. Depending on the test particle, glass filters or membrane filters were installed in the filter holders.

The overall dimensions of the RAS are listed in the table. The weight and power of the RAS were not measured, as this is a proof of concept device and not the final design.

The RAS and reference filters sampled the air for the same amount of time and the sampling efficiency was determined by comparing the amount of aerosol collected by the sampler to the reference filter. Air flow rate and liquid volume were taken into consideration in the sampling calculations.

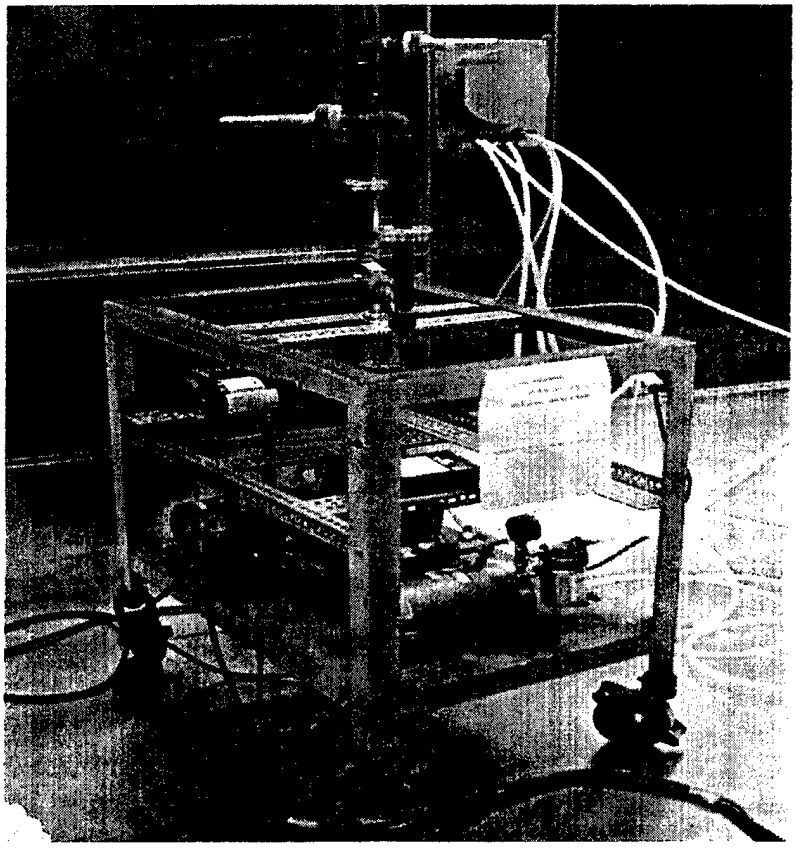

Figure 3. Rotating Arm Sampler.

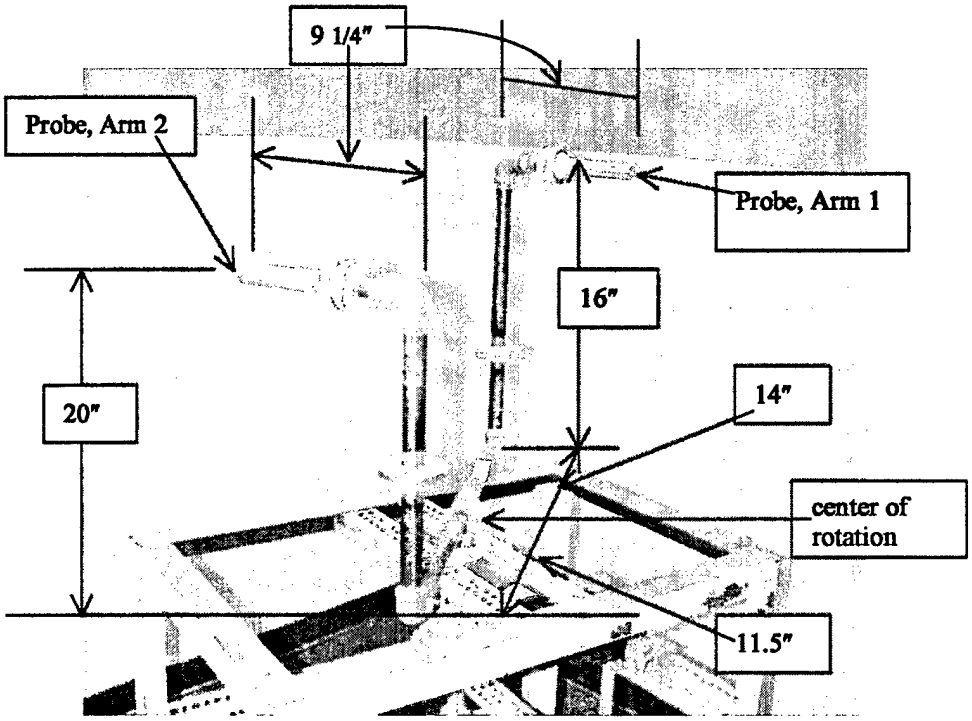

Figure 4. Enlarged view of the Rotating Arm Sampler. The length of the probe is 4" with an ID of 15/16"

3.3 BioCapture™ BT-500 Aerosol Sampler

The BioCapture™ BT-500 aerosol sampler is a portable, light weight, battery operated high volume sampler. A 12 V, 2.3 Ah rechargeable battery is used with this sampler. The air flow rate was measured to be 150 L/min using a Kurz flow meter (Kurz Instruments, Inc., Monterey, CA). Pictures of the sampler are shown in Figures 5 and 6. This sampler is 12" long, 6" wide, and 8" high. It has a handle for easy carrying. There are liquid cartridges (Figure 7) that contain prewash, sample collection, and sterilization liquids that can be obtained from the manufacturer. The sterilization liquids are in the red cartridges and the sample collection liquids are in white cartridges (shown in Figure 7). Because the solutions that are sold by the manufacturer are propriety information, we emptied the liquid in the cartridge and filled it with recovery solution to sample fluorescent oleic acid particles and water to sample fluorescent PSL particles. Our recovery solution did not have a surfactant in it. A detailed description on the use of fluorescent oleic acid particles in sampler characterization is given by Kesavan and Doherty (2001b).

The BioCapture™ nozzles were placed into the cartridge filled with recovery solution. The manufacture recommends that the user place 5 mL of prewash liquid in one compartment and 12 mL of sample collection liquid in the middle compartment. The sample is collected in the remaining compartment, Figure 7.

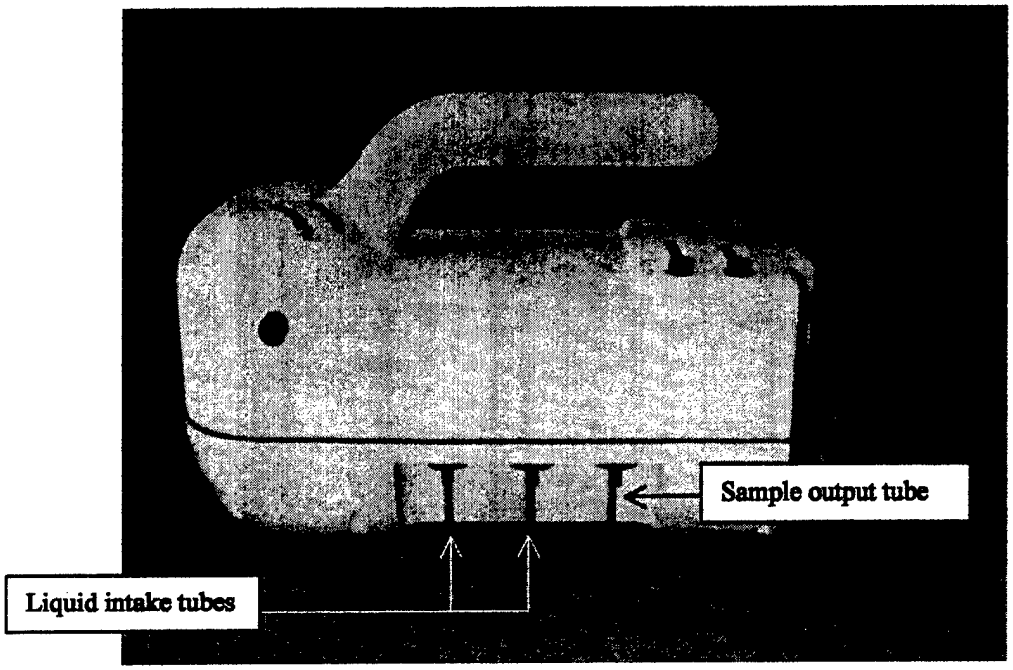

Figure 5. Side view of the BioCapture™ Aerosol Sampler.

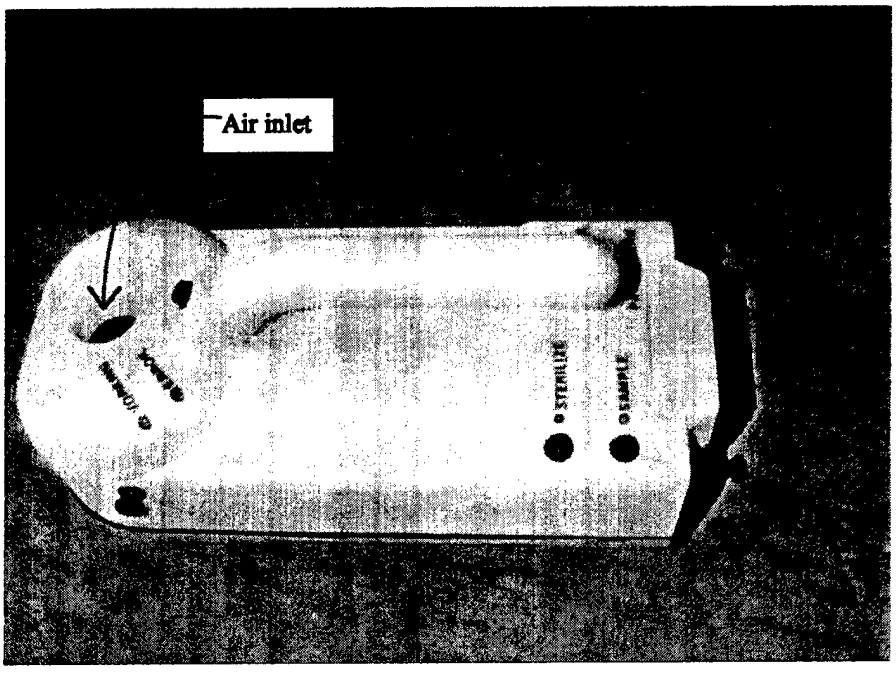

Figure 6. Top view of the BioCapture™ Aerosol Sampler showing air inlet.

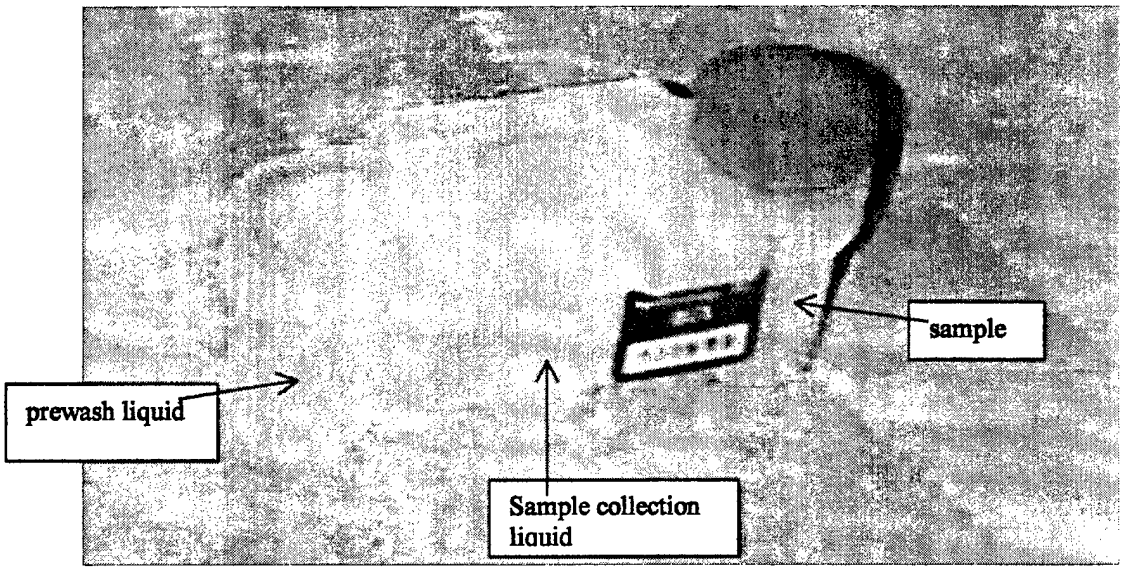

Figure 7. Cartridges containing the prewash and sample collection liquids used in the BioCapture™ Sampler.

The inlet is a 1 3/16" diameter opening that has a screen to prevent large particles and insects from entering the sampler. The sampling surface is a wetted rotating surface that has grooves to direct air and liquid flow. A sterilization cycle can be used for sterilizing the sampler before and after biological material sampling. The sterilization cycle takes a longer time than the sample cycle. The sample cycle has two modes. The first mode is a prewash and the second mode is the actual sampling. The system performs a prewash to remove particles from previous tests and to wet the surfaces and takes approximately 1¼ min. The actual sampling is conducted in the next 5¾ min. The complete sampling cycle, therefore, takes approximately 7 min. In the sampling efficiency testing, the BioCapture™ sampled clean air from outside of the chamber during the prewash mode. However, during the sample mode, the BioCapture™ and the reference filters sampled the aerosol from the chamber.

This was achieved by connecting a long tube connected to the outside of the chamber inlet of the BioCapture™ so that it will sample from the outside of the chamber for the first 1¼ min. Exactly at 1¼ min, the reference filters were turned on and the tube was removed from the BioCapture™, so that they all sampled from the chamber air.

During the prewash mode, the BioCapture™ pulls the prewash liquid from the prewash compartment and wets and washes the tubing and impaction surfaces and puts the liquid back in the prewash compartment. When the BioCapture™ is going through the sample mode, it pulls the sample collection liquid from the middle compartment and places the sample in the sample compartment.

Figure 8 shows a typical amount of particle removal from the sampler during the washing procedure. Nine micron particles were collected in the sampler in this study. Following the sample collection the washings were conducted by sampling from the clean room. Three washes were collected and analyzed during this study. A fourth wash was discarded. Wash number 3 has less than 5% of the

collected sample. From this study we can conclude that there is no significant amount of carry over from one test to the next. The size and weight of the sampler are listed in the table.

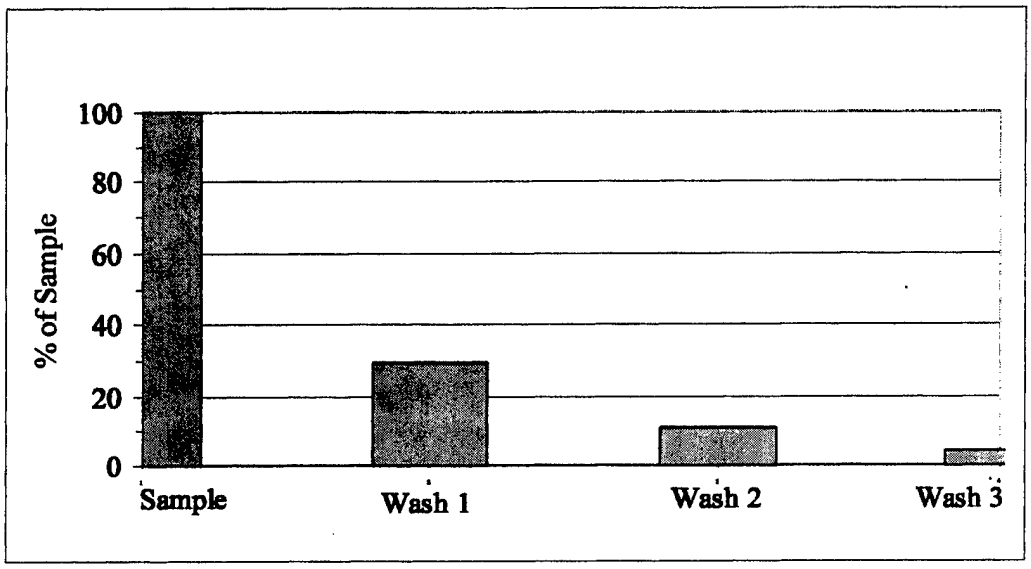

Figure 8. Particle removal from the BioCapture™ Sampler during the washing procedure. The wash was conducted by sampling from a clean chamber.

3.4 Microvic™ Aerosol Concentrator

Pictures of the Microvic™ Aerosol Concentrator are shown in Figures 9 and 10. Air enters the sampler through a slit on top at a flow rate of 30 L/min. There are two narrow slits on either sides of the sampler to pull the major air flow of 27 L/min out of the sampler. The minor air flow of 3 L/min passes out the bottom. A filter is attached to the output of the sampler to capture particles in the minor air flow. The Microvic™ Aerosol Concentrator that we tested did not come with blowers, therefore, laboratory vacuum pumps were used to pull the major air flow of 27 L/min and the minor flow of 3 L/min. The power consumption of the Microvic™ depends on the air blower and/or vacuum pump that is used, therefore, we did not measure the power consumption of the system.

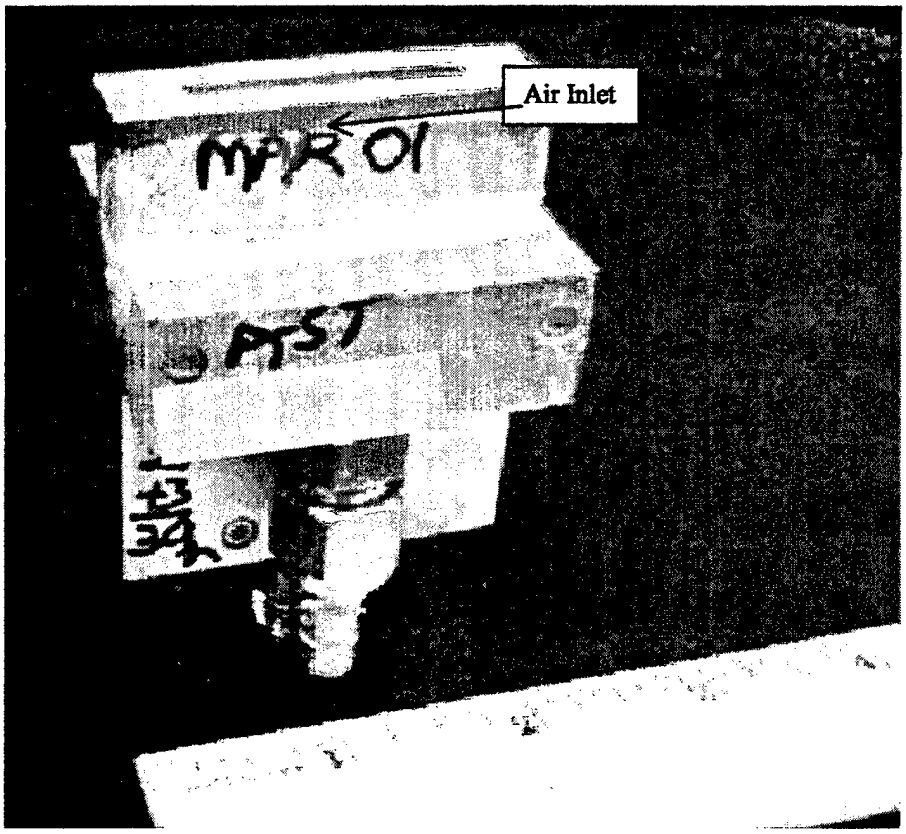

Figure 9. Picture of the Microvic™ Aerosol Concentrator. Air enters the Microvic™ through a slit opening.

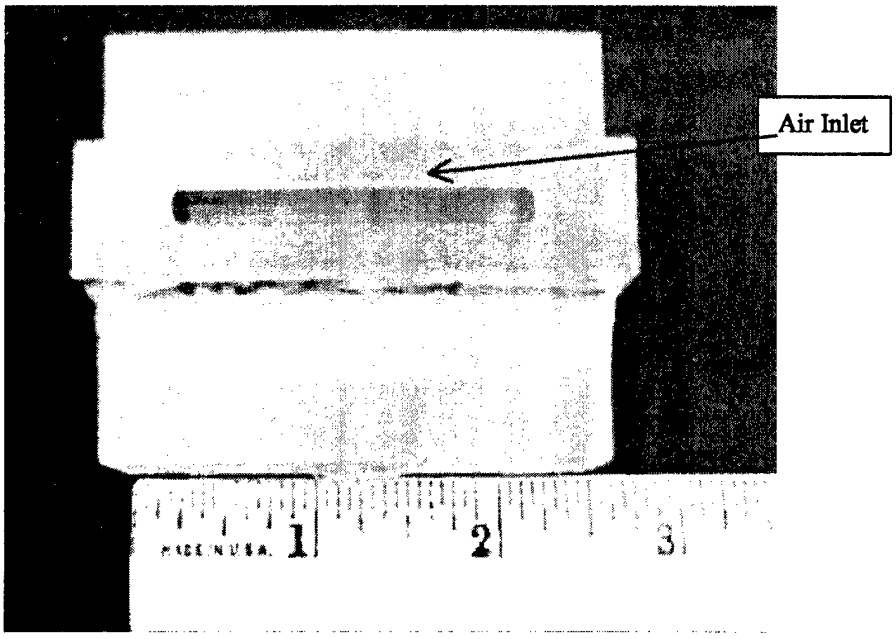

Figure 10. Top View of the Air Inlet on the Microvic™ Aerosol Concentrator.

4. RESULTS

The sampling efficiency results for the three samplers are shown in Figures 11 - 13. The air flow rate and liquid volumes were taken into account in the sampling efficiency calculations.

4.1 Rotating Arm Sampler

The sampling efficiency of the RAS was determined by comparing the sample collected by the sampler to that collected by the reference filter. The sampling efficiency results are shown in Figure 11. As the particle size increased from 2 μm to 13 μm, the sampling efficiency decreased from about 95% to 80%. In this study, we did not wash the probe to remove the deposited particles after each test, however, the probes were cleaned when the particle size was changed. Future studies should wash the probe and the liquid should be analyzed for fluorescence.

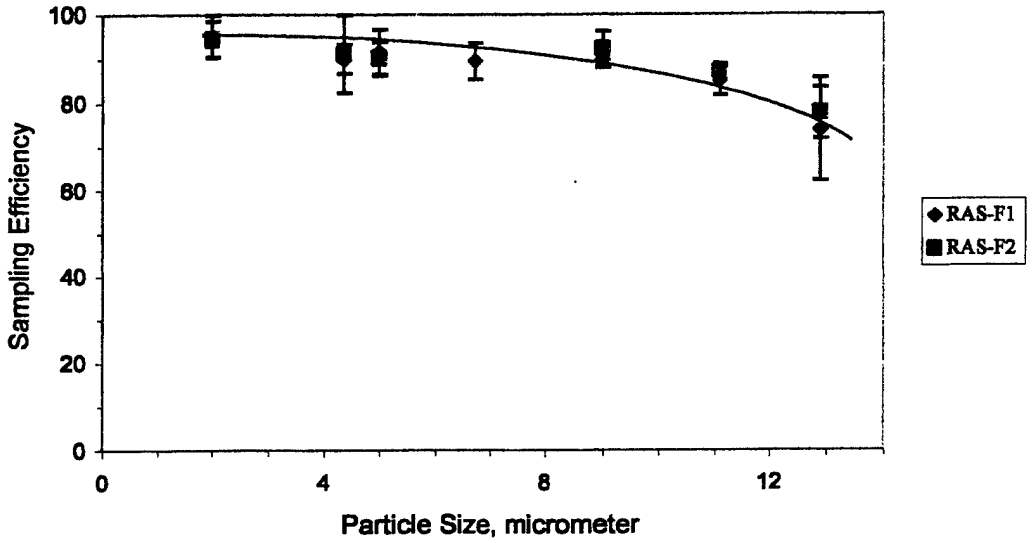

Figure 11. Sampling efficiency results of the Rotating Arm Sampler

4.2 BioCapture™ BT-500 Aerosol Sampler

The sampling efficiency for the BioCapture™ BT-500 Aerosol Sampler is shown in Figure 12. The highest sampling efficiency is 21.6% for 3.5 μm particles. For particle sizes between 1 to 5 μm the sampling efficiency is between 12% and 22%. For particle sizes between 5 to 5.5 μm the sampling efficiency decreases to around 5%.

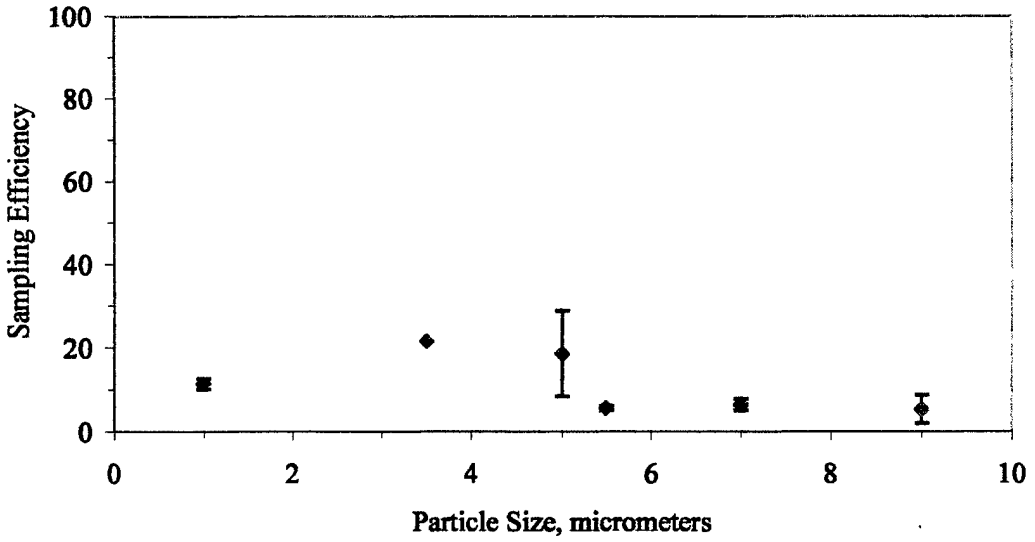

Figure 12. Sampling efficiency of the BioCapture™ Aerosol Sampler.

4.3 Microvic™ Aerosol Concentrator

The sampling efficiency of the Microvic™ Aerosol Concentrator is shown in Figure 13. The sampling efficiency is between 40 to 60 % for particles in the range of 1 to 11 μm.

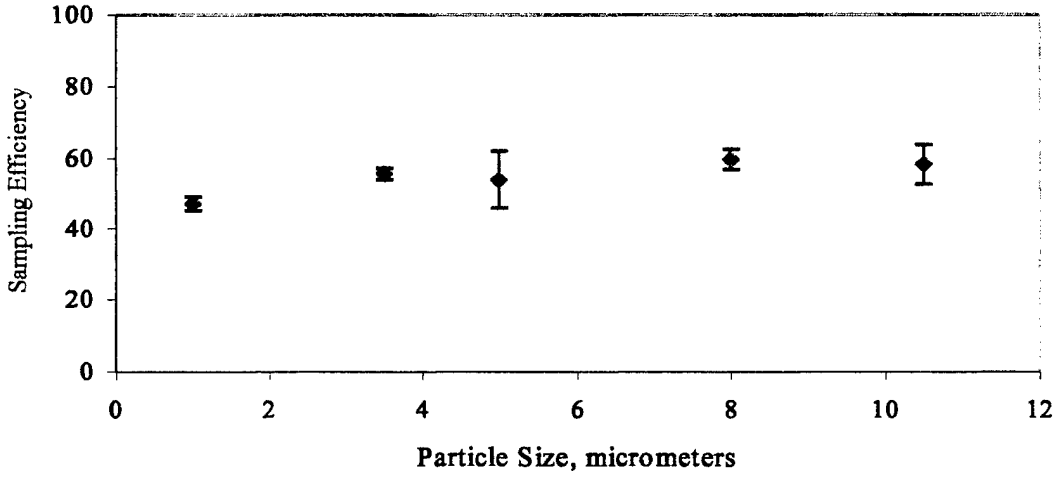

Figure 13. Sampling efficiency of the Microvic™ Aerosol Concentrator.

5. DISCUSSION AND CONCLUSIONS

Sampling efficiency results of the RAS shows that as the particle size increases the collection efficiency decreases due to the deposition of particles in the probe. During the RAS study, we did not wash the probe to remove deposited particles after each test, however, the probes were cleaned when the particle size was changed. Future RAS studies should wash the probe and the liquid should be analyzed for fluorescence.

There are several disadvantages with the RAS compared to the stationary open face filter. (1) It is necessary to ensure that the volumetric air flow rate and the volume covered by the probe opening per minute are similar to achieve isokinetic conditions. (2) Additional time and work is required to wash the probe, analyze the liquid and include it with the filter results. (3) It is time consuming to wash the probe between tests.

The BioCapture™ sampler is a light weight, portable, battery operated air sampler that is easy to operate. The disadvantage is that the user does not have control over the liquid feed rate. The sampling efficiency curve has a peak of 21.6% at 3.5 μm particles. A collection liquid without surfactant was used in these sampling efficiency tests. The use of surfactant may increase the wetting of the surfaces and increase the sampling efficiency results. The collection efficiency of the sampler depends on the power of the battery. Therefore, the user needs to make sure the battery is good. Three washes were conducted to remove particles from the sampler in between tests and the results showed that there is no carry over of particles between tests.

Currently, the Microvic™ Aerosol Concentrator is a small device. Adding blowers to it will make it somewhat larger. The sampling efficiency is between 40 and 60% for particles in the range of 1 - 11 μm. The sampling efficiency of the Microvic™ Aerosol Concentrator is higher compared to many other samplers we have tested, therefore, we believe the company should conduct additional research to complete and market the device.

LITERATURE CITED

Kesavanathan, J., and Doherty, R.W. (1999), *Test Procedure for Removing Polystyrene Latex Microspheres from Membrance Filters*, ECBC-TN-001, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Kesavan, J., and Doherty, R.W. (2001a), *Use of Fluorescein in Aerosol Studies*, ECBC-TR-103, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Kesavan, J., and Doherty, R.W. (2001b), *Comparison of Sampler Collection Efficiency Measurements Using a Polydisperse Solid Aerosol and a Monodisperse Liquid Aerosol*, ECBC-TR-137, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Olan-Figueroa, E., McFarland, A.R., and Ortiz, C.A. (1982), Flattening Coefficients for DOP and Oleic Acid Droplets Deposited on Treated Glass Slides," *Am. Ind. Hyg. Assoc. J.* Vol 43, pp 395-399.

DEPARTMENT OF THE ARMY
CDR USASBCCOM
ATTN AMSSB SCI C
5183 BLACKHAWK ROAD
APG MD 21010-5424

OFFICIAL BUSINESS

STANDARD B